

US011300086B2

(12) **United States Patent**
Incerpi et al.

(10) **Patent No.:** **US 11,300,086 B2**
(45) **Date of Patent:** **Apr. 12, 2022**

(54) **FUEL AND OIL SYSTEM**

9/26; F02C 9/46; F02C 9/30; F05D
2260/98; F05D 2270/094; F01D 25/20;
F01M 1/02; F02M 37/08; F02M
2037/085

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See application file for complete search history.

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 723 days.

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(21) Appl. No.: **15/446,584**

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(22) Filed: **Mar. 1, 2017**

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(65) **Prior Publication Data**

US 2017/0284351 A1 Oct. 5, 2017

EP 3 012 438 A1 4/2016
RU 2507407 C1 2/2014

(30) **Foreign Application Priority Data**

Mar. 30, 2016 (GB) 1605270

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(51) **Int. Cl.**

H02P 29/024 (2016.01)
F02C 7/22 (2006.01)
F02M 59/20 (2006.01)
H02P 6/04 (2016.01)
F02C 9/26 (2006.01)
F01D 25/20 (2006.01)

(Continued)

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(52) **U.S. Cl.**

CPC **F02M 59/20** (2013.01); **F01D 25/20** (2013.01); **F01M 1/02** (2013.01); **F02C 7/06** (2013.01); **F02C 7/22** (2013.01); **F02C 7/236** (2013.01); **F02C 9/26** (2013.01); **F02M 37/08** (2013.01); **H02K 9/00** (2013.01); **H02P 6/04** (2013.01); **H02P 29/024** (2013.01); **H02P 29/0241** (2016.02); **F01M 2001/0215** (2013.01); **F05D 2260/84** (2013.01); **Y02T 50/60** (2013.01)

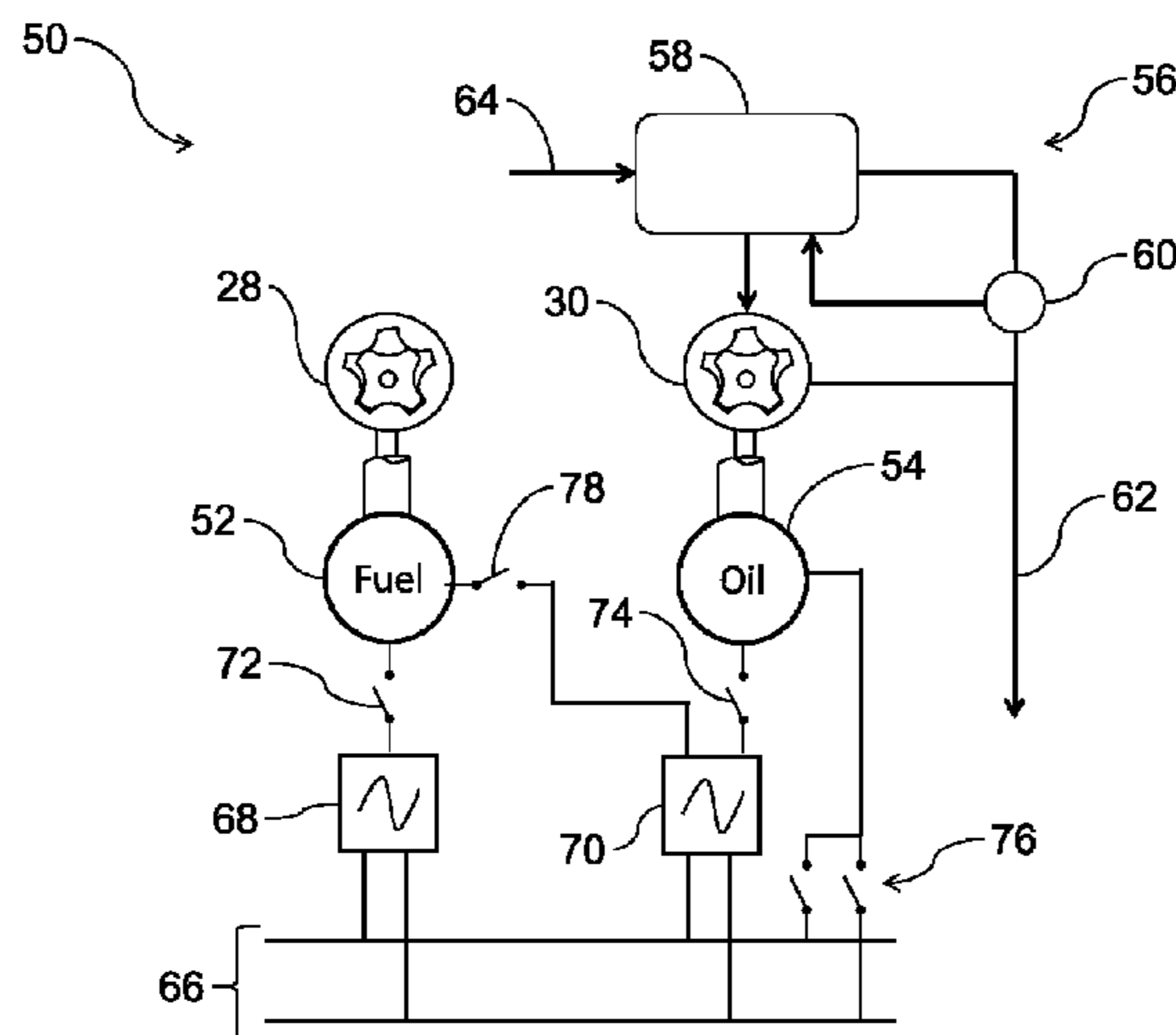
(57) **ABSTRACT**

A fuel and oil system includes a fuel pump, an oil pump, and a fixed electrical drive. A first electric motor controller of the fuel and oil system supplies a variable electrical drive, and a second electric motor controller supplies a variable electrical drive. The fuel pump is selectively connected to and driven by the first electric motor controller or the second electric motor controller. The oil pump is selectively connected to and driven by the second electric motor controller or the fixed electrical drive.

(58) **Field of Classification Search**

CPC F02C 7/22; F02C 7/32; F02C 7/236; F02C

9 Claims, 8 Drawing Sheets



- (51) **Int. Cl.**
F02C 7/236 (2006.01)
H02K 9/00 (2006.01)
F01M 1/02 (2006.01)
F02C 7/06 (2006.01)
F02M 37/08 (2006.01)

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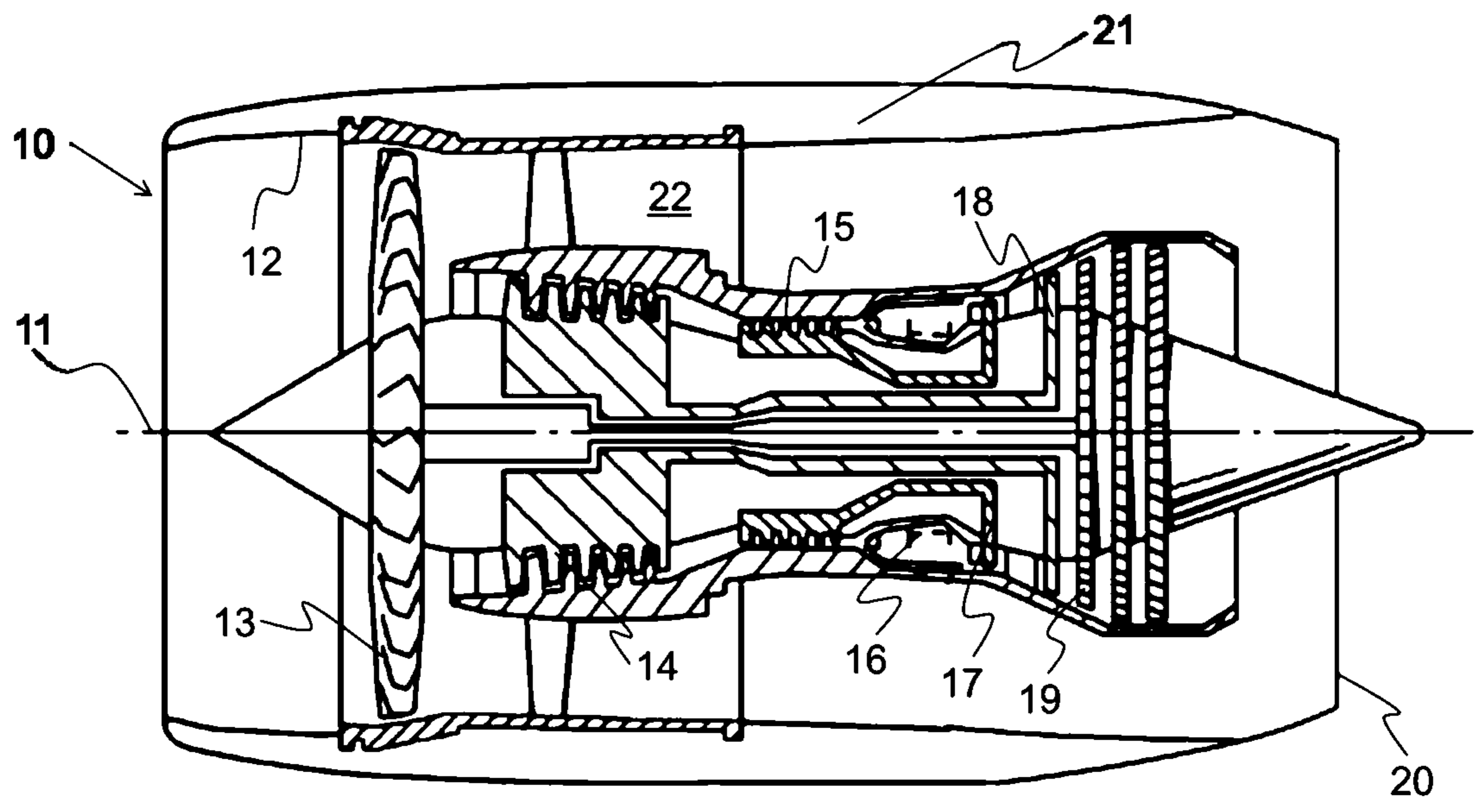


Figure 1

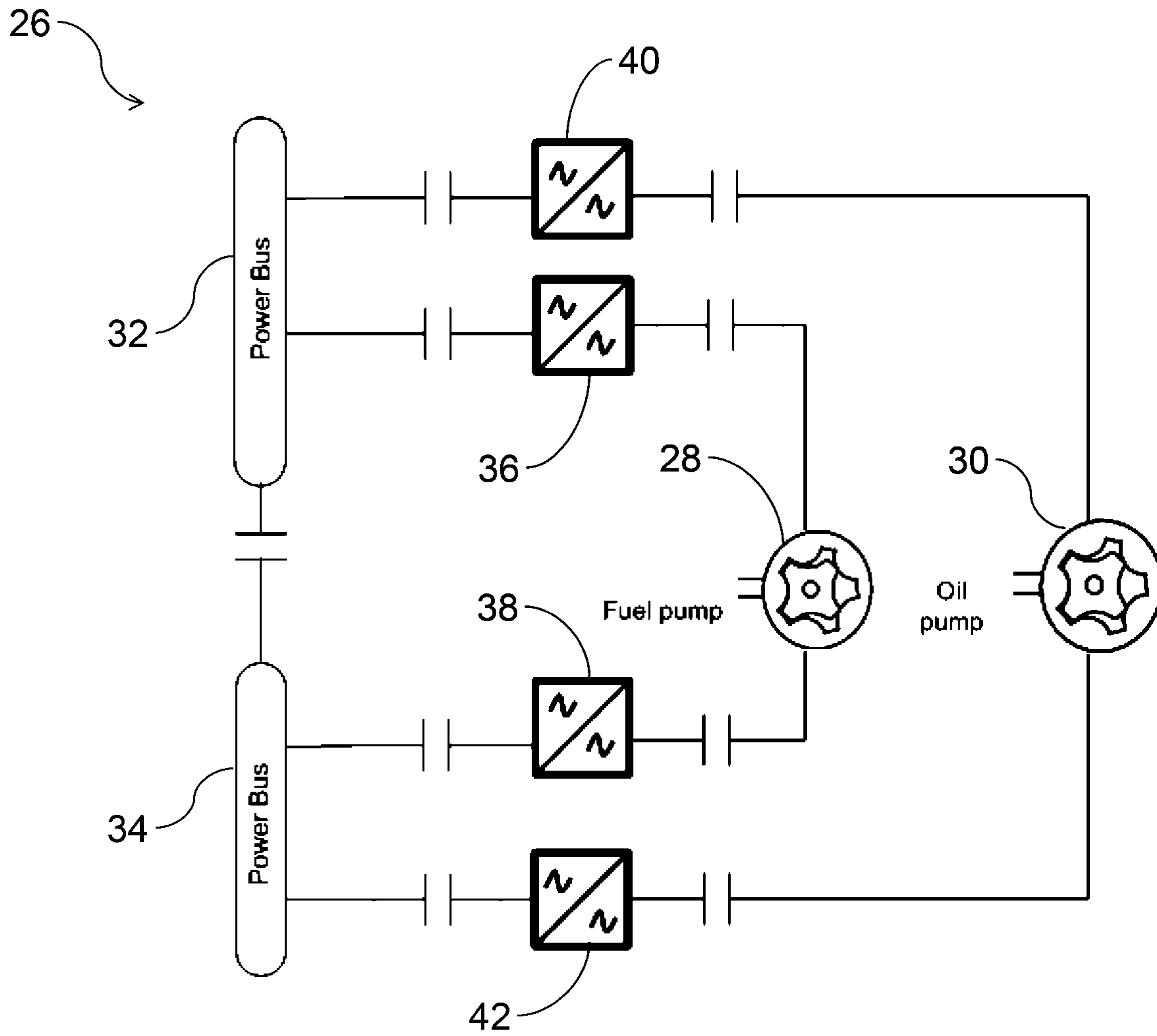


Figure 2: Related Art

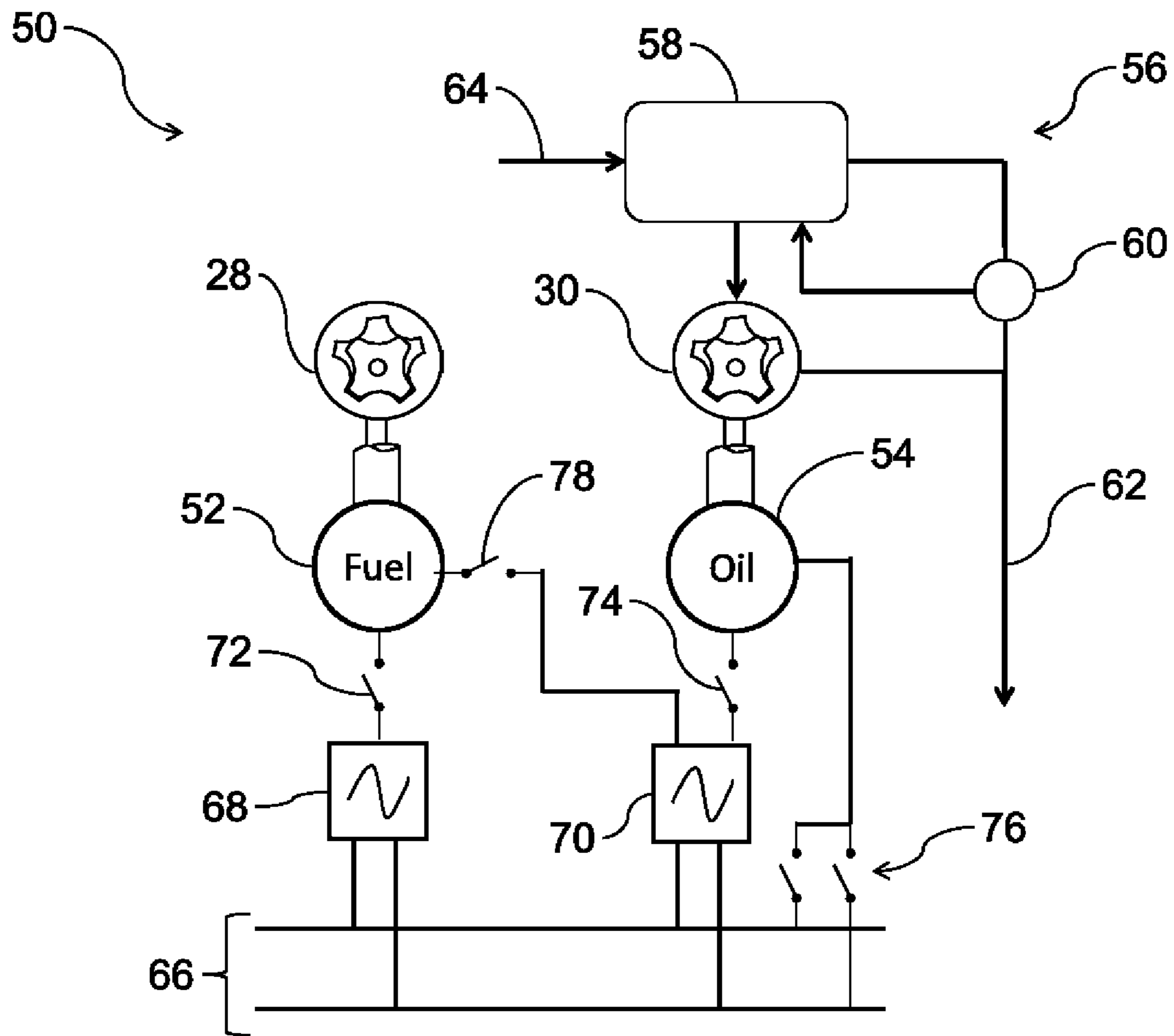


Figure 3

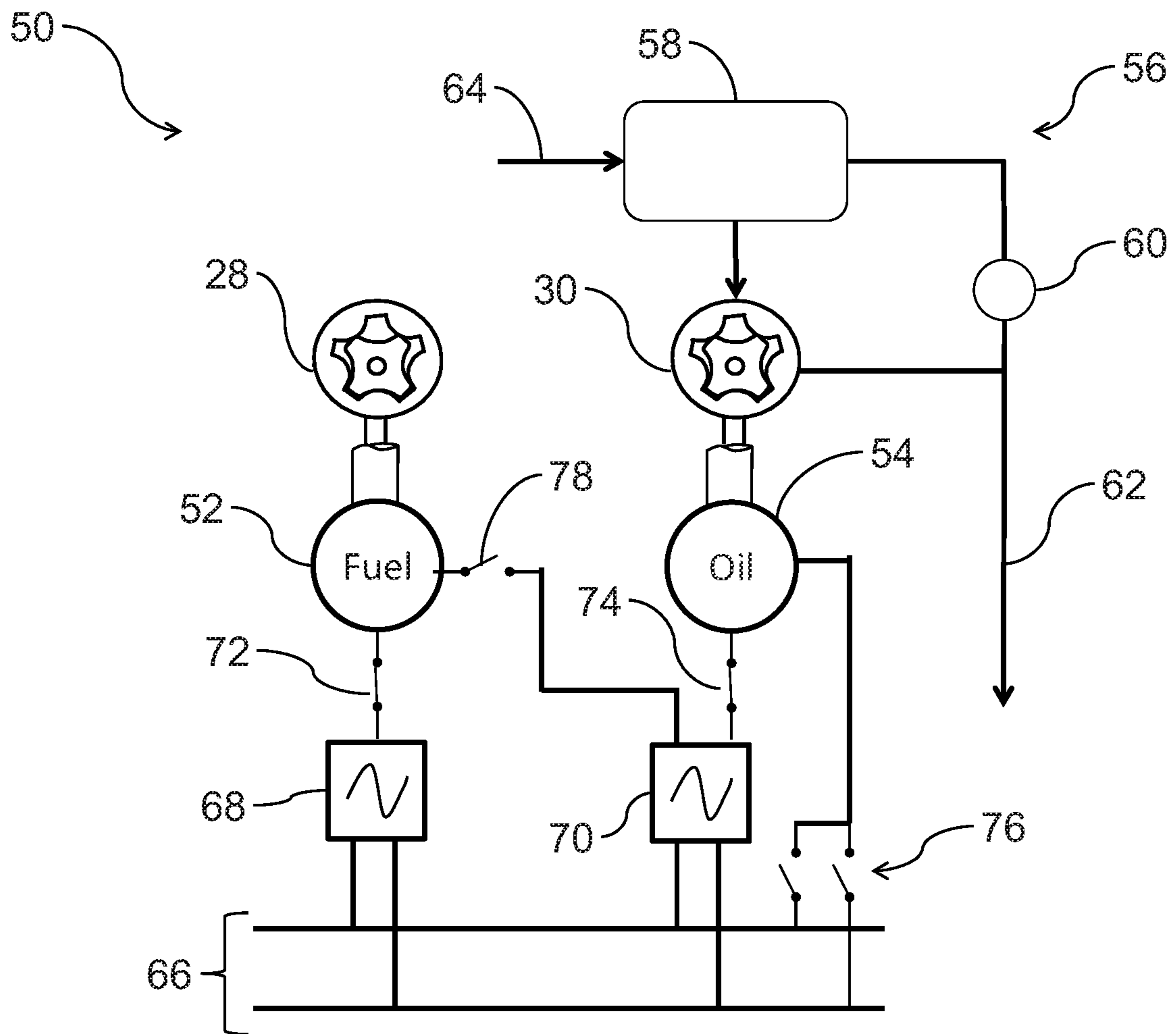


Figure 4

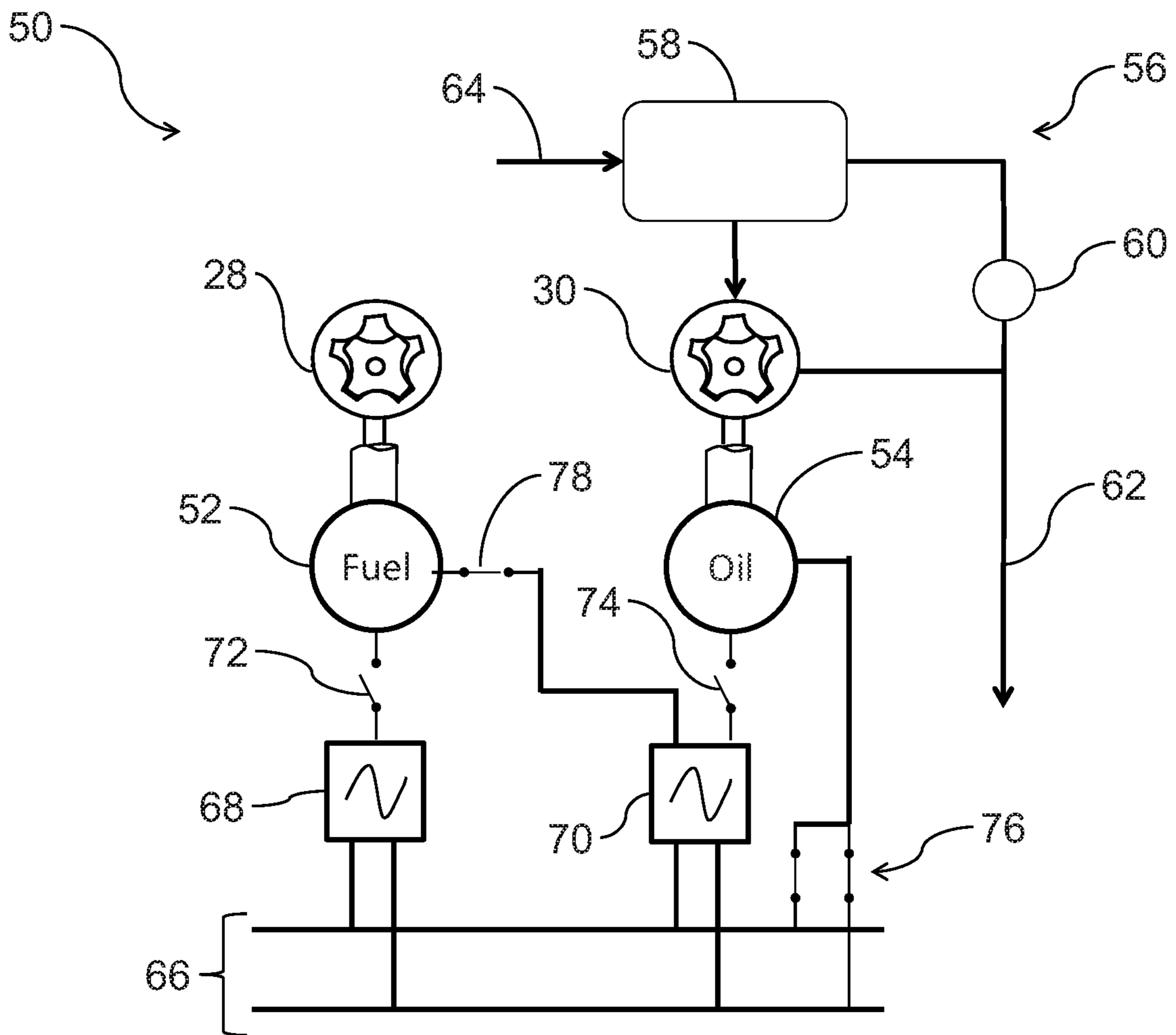


Figure 5

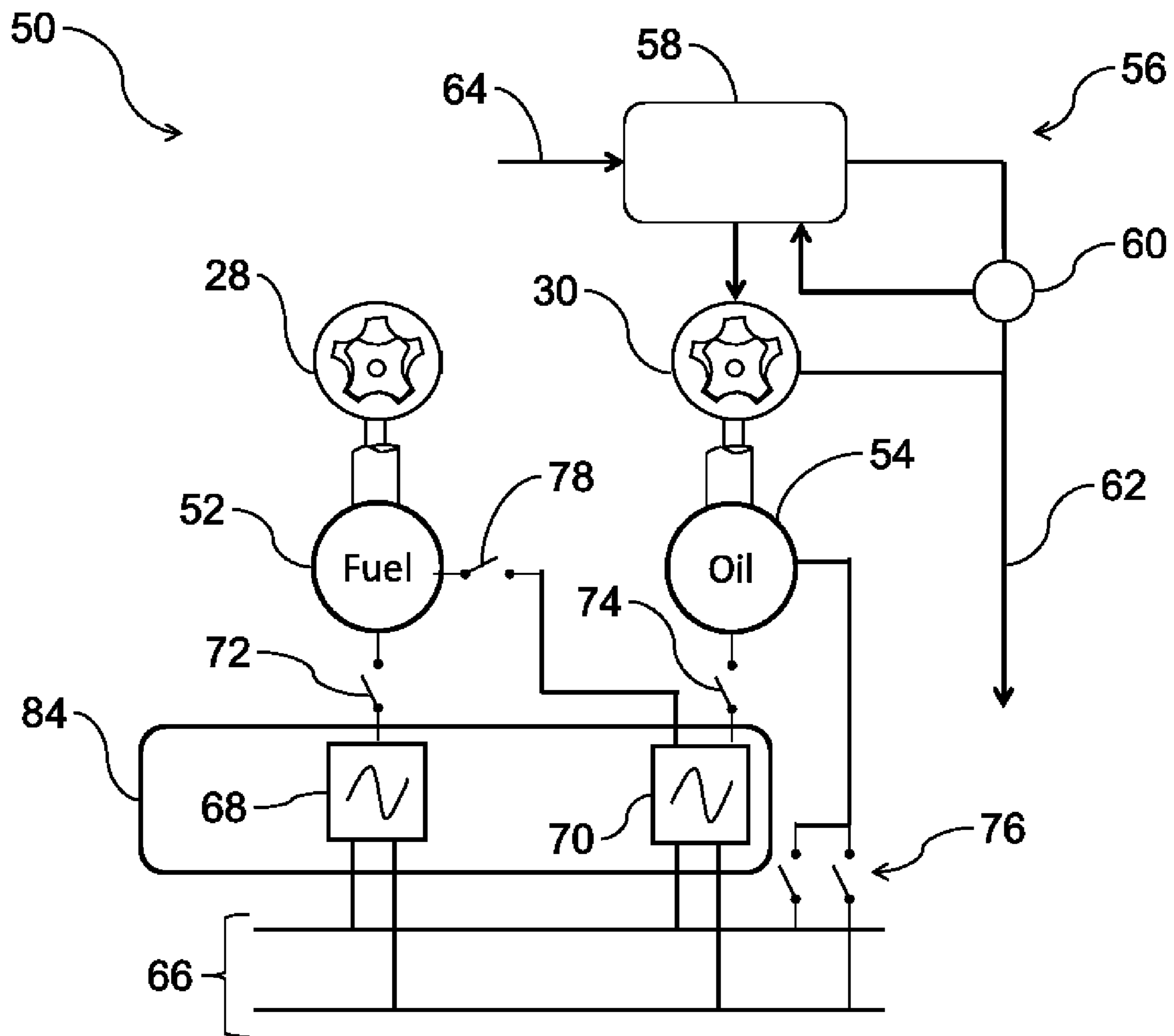


Figure 8

1**FUEL AND OIL SYSTEM**

The present disclosure concerns a fuel and oil system. In particular, but not exclusively, it concerns a fuel and oil system for a gas turbine engine.

BACKGROUND

In a gas turbine engine it is known to have a fuel system including a fuel pump driven at variable speed by a motor. The motor is controlled by a controller. Similarly it is common to have an oil system including an oil pump driven at fixed or variable speed by a motor. Where the motor drives at variable speed it is also controlled by a controller.

Generally it is considered critical that the variable speed control of the fuel system is maintained throughout operation of the gas turbine engine. Therefore it is common to provide two motors and controllers to drive the fuel system in order to provide redundancy. Although variable speed control of the oil system is less critical it is still common to duplicate the oil system motor and controller for redundancy.

Motors for fuel and oil systems may be hydraulically or mechanically driven. However, there is a desire to move towards electrically driven motors.

SUMMARY

According to a first aspect of the present invention there is provided a fuel and oil system comprising:

- a fuel pump;
- an oil pump;
- a first electric motor controller configured to supply a variable electrical drive;
- a second electric motor controller configured to supply a variable electrical drive; and
- a fixed electrical drive;

wherein the fuel pump is selectively connected to and driven by the first electric motor controller or the second electric motor controller; and

wherein the oil pump is selectively connected to and driven by the second electric motor controller or the fixed electrical drive.

In a first configuration of the system the fuel pump is connected to and driven by the first electric motor controller and the oil pump is connected to and driven by the second electric motor controller. Advantageously the system provides independent, fully variable control of the fuel pump and oil pump. Advantageously this enables each of the fuel system and the oil system to operate at efficient pump speed and optimal flow rates so there is little or no excess supply and consequential spill back of fuel or oil.

In a second configuration of the system the fuel pump is connected to and driven by the second electric motor controller and the oil pump is connected to and driven by the fixed electrical drive. Advantageously, when the first electric motor controller is faulty and so unable to control the fuel pump, the system maintains fully variable control of the fuel pump by switching it to the second electric motor controller instead of the first electric motor controller. Advantageously there is no requirement for a normally-redundant variable electrical drive motor controller for the fuel pump.

In a third configuration of the system the fuel pump is connected to and driven by the first electric motor controller and the oil pump is connected to and driven by the fixed electrical drive. Advantageously, when the second electric motor controller is faulty and so unable to control the oil

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pump, the system maintains fully variable control of the fuel pump but switches the oil pump control to the fixed electrical drive instead of the second electric motor controller. Advantageously there is no requirement for a normally-redundant variable electrical drive motor controller for the oil pump.

Advantageously the system provides electrical drive to the fuel pump and the oil pump in any operational mode. Advantageously both the fuel pump and oil pump have redundancy of control. Advantageously variable electrical drive is maintained to the fuel pump by switching from variable to fixed electrical drive for the oil pump if one of the variable electrical motor controllers fails. Advantageously the system includes fewer components than in known arrangements without sacrificing redundancy, and therefore safety, and whilst maintaining variable control of the fuel pump.

The system may comprise a spill valve connected to an output of the oil pump. Advantageously excess oil can be spilt to an oil tank and reused. Advantageously the oil pump can be configured to run at maximum flow rates without penalty so that it can be operated via the fixed electrical drive for extended periods of time. The spilt oil may be cooled before being delivered to the oil tank. Advantageously this reduces the overall temperature of oil in the oil system.

The first electric motor controller and the second electric motor controller may be different. Advantageously this reduces the potential for common mode faults affecting both the first and second electric motor controllers. Alternatively the first electric motor controller and the second electric motor controller may be the same type. Advantageously this means the electric motor controllers are interchangeable which reduces the part count and thus the required spare part stock. It also ensures that the first and second electric motor controllers are wholly substitutable and therefore provides good redundancy.

The system may further comprise a cooling arrangement. The cooling system may comprise a first cooling loop arranged to cool the first electric motor controller and a second cooling loop arranged to cool the second electric motor controller. Advantageously each cooling loop may be optimised to the electric motor controller it is arranged to cool. Alternatively the cooling system may comprise a common cooling loop arranged to cool both the first electric motor controller and the second electric motor controller. Advantageously the common cooling loop may comprise fewer parts than two separate loops.

There is also provided a gas turbine engine comprising a fuel and oil system as described above. There is also provided a diesel engine comprising a fuel and oil system as described above.

The skilled person will appreciate that except where mutually exclusive, a feature described in relation to any one of the above aspects may be applied mutatis mutandis to any other aspect. Furthermore except where mutually exclusive any feature described herein may be applied to any aspect and/or combined with any other feature described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments will now be described by way of example only, with reference to the Figures, in which:

- FIG. 1 is a sectional side view of a gas turbine engine;
- FIG. 2 is a schematic illustration of a dual redundant fuel and oil system;

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FIG. 3 is a schematic illustration of a fuel and oil system as described herein;

FIG. 4 is a schematic illustration of the system of FIG. 3 in a first configuration;

FIG. 5 is a schematic illustration of the system of FIG. 3 in a second configuration;

FIG. 6 is a schematic illustration of the system of FIG. 3 in a third configuration;

FIG. 7 is a schematic illustration of the fuel and oil system as described herein including a cooling arrangement in a first configuration; and

FIG. 8 is a schematic illustration of the fuel and oil system as described herein including a cooling arrangement in a second configuration.

DETAILED DESCRIPTION

With reference to FIG. 1, a gas turbine engine is generally indicated at 10, having a principal and rotational axis 11. The engine 10 comprises, in axial flow series, an air intake 12, a propulsive fan 13, an intermediate pressure compressor 14, a high-pressure compressor 15, combustion equipment 16, a high-pressure turbine 17, an intermediate pressure turbine 18, a low-pressure turbine 19 and an exhaust nozzle 20. A nacelle 21 generally surrounds the engine 10 and defines both the intake 12 and the exhaust nozzle 20.

The gas turbine engine 10 works in the conventional manner so that air entering the intake 12 is accelerated by the fan 13 to produce two air flows: a first air flow into the intermediate pressure compressor 14 and a second air flow which passes through a bypass duct 22 to provide propulsive thrust. The intermediate pressure compressor 14 compresses the air flow directed into it before delivering that air to the high pressure compressor 15 where further compression takes place.

The compressed air exhausted from the high-pressure compressor 15 is directed into the combustion equipment 16 where it is mixed with fuel and the mixture combusted. The resultant hot combustion products then expand through, and thereby drive the high, intermediate and low-pressure turbines 17, 18, 19 before being exhausted through the nozzle 20 to provide additional propulsive thrust. The high 17, intermediate 18 and low 19 pressure turbines drive respectively the high pressure compressor 15, intermediate pressure compressor 14 and fan 13, each by suitable interconnecting shaft.

Other gas turbine engines to which the present disclosure may be applied may have alternative configurations. By way of example such engines may have an alternative number of interconnecting shafts (e.g. two) and/or an alternative number of compressors and/or turbines. Further the engine may comprise a gearbox provided in the drive train from a turbine to a compressor and/or fan.

FIG. 2 shows a commonly used dual redundant motor control system 26. A fuel pump 28 is driven by an electric motor (not shown). An oil pump 30 is driven by an electric motor (not shown). A first power bus 32 is arranged to provide electrical power. A second power bus 34 is arranged to provide electrical power independently of the first power bus 32. The motor for the fuel pump 28 is controlled by a first electric motor controller 36 or a second electric motor controller 38. The first electric motor controller 36 is powered by the first power bus 32 whereas the second electric motor controller 38 is powered by the second power bus 34. Thus one of the first and second electric motor controllers 36, 38 is usually used to drive the electric motor of the fuel pump 28 and the other of the first and second electric motor

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controllers 36, 38 is normally dormant but is available to take over control in the event of failure of the usually driving electric motor controller 36, 38. The fuel pump 28 has redundant motor control.

Similarly the motor for the oil pump 30 is controlled by a third electric motor controller 40 or a fourth electric motor controller 42. The third electric motor controller 40 is powered by the first power bus 32 whereas the fourth electric motor controller 42 is powered by the second power bus 34. Thus one of the third and fourth electric motor controllers 40, 42 is usually used to drive the electric motor of the oil pump 30 and the other of the third and fourth electric motor controllers 40, 42 is normally dormant but is available to take over control in the event of failure of the usually driving electric motor controller 40, 42. The oil pump 30 thus also has redundant motor control. The motor control system 26 is therefore a dual redundant system.

In a gas turbine engine 10, particularly a gas turbine engine 10 used to power an aircraft, it is beneficial to reduce the number of motor controllers 36, 38, 40, 42 to reduce weight. However, it is also important not to sacrifice the safety provided by motor controller redundancy. The fuel and oil system 50 of the present invention addresses these considerations.

The fuel and oil system 50 is illustrated in FIG. 3. The fuel pump 28 is driven by an electric fuel motor 52. The oil pump 30 is similarly driven by an electric oil motor 54. Part of the oil system 56 is shown. An oil tank 58 delivers oil to the oil pump 30 which pumps the oil to the engine 10, arrow 62. When an excess of oil is pumped a spill valve 60 is opened to spill some of the oil back to the oil tank 58, which incurs some additional heating of the oil. The oil system 56 is generally closed loop. Therefore, the oil tank 58 is supplied from scavenge of oil which has been used in the engine 10, as indicated by arrow 64.

The fuel system is not shown for simplicity. Broadly fuel is supplied from a fuel tank to the fuel pump 28 which delivers fuel to combustor 16 of the engine 10. The fuel system is open loop, although if excess fuel is provided to the fuel pump 28 it can be spilled back to the fuel tank. It is beneficial not to oversupply fuel to the fuel pump 28 as the act of pumping it works the fuel and therefore heats it and increases the cooling requirement in the fuel system 52 and the oil system 54.

A power source 66 is illustrated as two busbars. Other forms of suitable power source 66 can be substituted with equal felicity.

A first electric motor controller 68 is connected to the power source 66. The first electric motor controller 68 is a variable controller. It is configured to supply electrical drive at a variable output speed or frequency. The first electric motor controller 68 is selectively electrically coupled to or connected to the electric fuel motor 52 to drive the motor 52 and thence the fuel pump 28 at a variable speed as required by the engine control system. A first switch 72 may be provided between the first electric motor controller 68 and the electric fuel motor 52. Closing the first switch 72 electrically couples or connects the first electric motor controller 68 to the electric fuel motor 52 while opening the first switch 72 electrically isolates the electric fuel motor 52 from the first electric motor controller 68.

A second electric motor controller 70 is connected to the power source 66. The second electric motor controller 70 is also a variable controller. It is configured to supply electrical drive at a variable output speed or frequency. The second electric motor controller 70 is selectively electrically coupled to or connected to the electric oil motor 54 to drive

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the motor **54** and thence the oil pump **30** at a variable speed as required by the engine control system. A second switch **74** may be provided between the second electric motor controller **70** and the electric oil motor **54**. Closing the second switch **74** electrically couples or connects the second electric motor controller **70** to the electric oil motor **54** while opening the second switch **74** electrically isolates the electric oil motor **54** from the second electric motor controller **70**.

The second electric motor controller **70** is also selectively electrically coupled to or connected to the electric fuel motor **52** to drive the motor **52** and thence the fuel pump **28** at a variable speed. In the event of a fault in the first electric motor controller **68** the second electric motor controller **70** can be coupled to the electric fuel motor **52** to provide the variable electrical drive so that fully variable control is possible in all operational conditions. The first electric motor controller **68** can be isolated from the electric fuel motor **52** by opening first switch **72**. The second electric motor controller **70** can be electrically coupled or connected to the electric fuel motor **52** by closing a third switch **78**.

The fuel and oil system **50** also includes a fixed electrical drive **76**. The fixed electrical drive **76** is selectively electrically coupled or connected to the electric oil motor **54** to drive the motor **54** and thence the oil pump **30** at a constant speed. The fixed electrical drive **76** may comprise, as illustrated, a pair of switches to directly electrically couple or connect the power source **66** to the electric oil motor **54**. It is less efficient to drive the oil pump **30** at constant speed because excess oil is pumped and therefore heated which must be spilt through the spill valve **60** back to the oil tank **58**. Preferably the spilt oil should be cooled before being delivered back to the oil tank **58** to reduce the overall temperature of the oil in the oil system **56**.

FIG. **4** shows the system of FIG. **3** in a first operating configuration. In the first configuration there are no faults in the fuel and oil system **50**. The electric fuel motor **52** is electrically coupled to or connected to the first electric motor controller **68** via closed first switch **72**. The electric oil motor **54** is electrically coupled to or connected to the second electric motor controller **70** via closed second switch **74**. Third switch **78** is open so that there is no electrical connection from the second electric motor controller **70** to the electric fuel motor **52**. The fixed electrical drive **76** is electrically disconnected or decoupled from the electric oil motor **54**, for example by opening the switches.

In the first configuration the fuel and oil system **50** provides independent, fully variable control of the electric fuel motor **52** and fuel pump **28**, and of the electric oil motor **54** and oil pump **30**. Advantageously this enables each part of the system, the fuel system and the oil system **56**, to be operated at an efficient pump speed and to minimise cooling requirements by minimising the excess supply and consequential spill back of fuel or oil.

FIG. **5** shows the system of FIG. **3** in a second operating configuration. In the second configuration there is a fault in the first electric motor controller **68**, which is therefore unable to control the electric fuel motor **52**. In order to maintain fully variable control of the electric fuel motor **52** the electrical connection to the faulty first electric motor controller **68** is isolated by opening the first switch **72** and the electric fuel motor **52** is instead electrically coupled or connected to the second electric motor controller **70** by closing the third switch **78**. At the same time the second switch **74** is opened to isolate the electric oil motor **54** from the second electric motor controller **70**, so that the second electric motor controller **70** is not overloaded, and the

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electric oil motor **54** is electrically coupled or connected to the fixed electrical drive **76**, by closing the switches.

In the second configuration, therefore, there is fully variable control of the electric fuel motor **52** and fuel pump **28** but the oil pump **30** is operated at fixed speed by the electric oil motor **54**. Advantageously both the fuel system and oil system **56** have redundancy of control. The second configuration sacrifices variable control of the oil system **56** in order to maintain fully variable control of the electric fuel motor **52** and fuel pump **28** without having to provide a normally-redundant variable output motor controller for the fuel system.

FIG. **6** shows the fuel and oil system **50** in a third configuration. In the third configuration there is a fault in the second electric motor controller **70**, which is therefore unable to control the electric oil motor **54**. The first electric motor controller **68** is unaffected and therefore fully variable control of the electric fuel motor **52** is provided, as in the first configuration, by the first electric motor controller **68** through closed first switch **72**. Both the second and third switches **74**, **78** are opened to isolate the faulty second electric motor controller **70** from the electric fuel motor **52** and from the electric oil motor **54**. Instead the fixed electrical drive **76** is electrically coupled or connected to the electric oil motor **54**, for example by closing the switches, in order that the electric oil motor **54** can drive the oil pump **30** at constant speed.

In the third configuration, therefore, there is fully variable control of the electric fuel motor **52** and fuel pump **28** but the oil pump **30** is operated at fixed speed by the electric oil motor **54**. Advantageously both the fuel system and oil system **56** have redundancy of control. The third configuration sacrifices variable control of the oil system **56** and so does not have to provide a normally-redundant variable output motor controller for the oil system **56**.

Advantageously the fuel and oil system **50** as described has operating configurations suitable for normal running and which account for failure of the first or second electric motor controllers **68**, **70**. In each operating configuration fully variable control of the fuel system is maintained. Where necessary variable control of the oil system **56** is replaced by fixed speed control of the oil pump **30** because the oil can be more easily cooled.

Advantageously the fuel and oil system **50** as described requires only two variable output electric motor controllers **68**, **70** compared to the arrangement described with respect to FIG. **2** which has four such motor controllers **36**, **38**, **40**, **42**. Consequently there is a benefit in terms of weight, cooling requirements, part count and complexity without sacrificing redundancy in the control of each part of the system **50**. The fuel pump **28** and oil pump **30** are controlled independently so each can be driven at an optimal speed in the first configuration. The fuel pump **28** can also be driven at an optimal speed in the second and third configurations where one or the other of the first and second electric motor controllers **68**, **70** is faulty.

The fixed electrical drive **76** is set at a size to provide sufficient electrical power to the electric oil motor **54** to drive the oil pump **30** for the most severe operating conditions. Where the fuel and oil system **50** forms part of a gas turbine engine **10** to power an aircraft the fastest (most severe) speed requirement for the oil pump **30** is at maximum take-off thrust. Thus both the fixed electrical drive **76** and the electric oil motor **54** are sized to supply sufficient power to operate the oil pump **30** at the maximum take-off speed for extended operation. Advantageously this ensures that where the fuel and oil system **50** must operate in the

second or third configuration due to a fault in the first or second electric motor controller **68**, **70** it is not necessary to restrict operation of the gas turbine engine **10**. Alternatively a smaller fixed electrical drive **76** may be provided and suitable restrictions placed on operation of the gas turbine engine **10** to compensate when the fuel and oil system **50** is operated in the second or third configurations.

Where the power source **66** is multiphase, for example three-phase, a coarse level of speed control can be provided for the oil pump **30** by the fixed electrical drive **76**. The fixed electrical drive **76** may supply one or more of the phases of the power source **66** to the electric oil motor **54** and therefore provide more than one constant power level to drive the oil pump **30**. The oil pump **30** can therefore be driven at a finite number of speeds corresponding to the number of phases available in the power source **66** which can be switched in or out by the fixed electrical drive **76**. This contrasts to the operation in the first configuration where the oil pump **30** is controlled fully variably. By providing more than one constant speed of operation of the oil pump **30** in the second and third configurations of the fuel and oil system **50** the oversupply of oil, and consequent spill back and cooling requirements, can be reduced. Some oversupply is still expected since it is unlikely that the available constant speeds corresponding to the phases of the power source **66** will match all (or even any) of the desired speeds for operation of the oil pump **30**. Advantageously a single phase of the power source **66** could be arranged to correspond to the minimum speed requirement of the oil pump **30**.

Optionally the fuel and oil system **50** may include a controller or control function which actively manages opening and closing of the first, second and third switches **72**, **74**, **78** and electrical coupling or connection of the fixed electrical drive **76**. Advantageously this may smooth the input to the electric fuel motor **52** during switching between the first and second electric motor controllers **68**, **70** and/or may smooth the input to the electric oil motor **54** during switching between the second electric motor controller **70** and the fixed electrical drive **76**.

Alternatively the electrical coupling or connection, and decoupling or disconnection, of the electric fuel and oil motors **52**, **54** to the first and second electric motor controllers **68**, **70** and fixed electrical drive **76** may be managed passively. That means that the electric fuel motor **52** may be arranged or configured to try to draw power from the second electric motor controller **70** when no power or a reduced amount of power is being supplied from the first electric motor controller **68**, and similarly the electric oil motor **54** may be arranged or configured to try to draw power from the fixed electrical drive **76** when no power or a reduced amount of power is being supplied from the second electric motor controller **70**.

The first electric motor controller **68** may be identical to the second electric motor controller **70** so that they are entirely interchangeable. Advantageously this reduces the part count of the fuel and oil system **50**. Advantageously it also ensures that the controllers **68**, **70** are wholly substitutable and therefore provide excellent redundancy.

Alternatively the first electric motor controller **68** may differ from the second electric motor controller **70**. The available power output of each controller **68**, **70** may be the same to provide the redundancy to permit either controller **68**, **70** to drive either the electric fuel motor **52** or the electric oil motor **54**. The second electric motor controller **70** may have a larger maximum power output than the first electric motor controller **68** in order to absorb any demand surge during switching from controlling the electric oil motor **54**

to controlling the electric fuel motor **52** (switching from the first to the second configurations of the fuel and oil system **50**). Advantageously, by providing dissimilar electric motor controllers **68**, **70** common mode failures are reduced or eliminated. Thus where an external event causes failure of the first electric motor controller **68** the second electric motor controller **70** may not be affected and vice versa.

As shown in FIGS. **7** and **8**, the fuel and oil system **50** may include a first cooling loop **80** arranged to cool the first electric motor controller **68** and a second cooling loop **82** arranged to cool the second electric motor controller **70**. Advantageously, each cooling loop **80/82** may be optimized to the respective electric motor controller **68/70** it is arranged to cool. Alternatively, the fuel and oil system **50** may include a single common cooling loop **84** arranged to cool both the first electric motor controller **68** and the second electric motor controller **70**. Advantageously, the common cooling loop **84** may include fewer parts than two separate loops **80/84**.

The fuel and oil system **50** finds particular applicability in a gas turbine engine **10** for powering an aircraft because it provides full redundancy with significant weight reduction compared to the motor control system **26** shown in FIG. **2**. However, it also finds application in gas turbine engines **10** used for other purposes, for example for marine and industrial applications; and in gas and diesel engines.

The fuel and oil system **50** also finds application in other industries in which two separate fluid pumping systems each have variable speed control of the pumps but one system can tolerate fixed speed control.

It will be understood that the invention is not limited to the embodiments above-described and various modifications and improvements can be made without departing from the concepts described herein. Except where mutually exclusive, any of the features may be employed separately or in combination with any other features and the disclosure extends to and includes all combinations and sub-combinations of one or more features described herein.

The invention claimed is:

1. A fuel and oil system comprising: a fuel pump; an oil pump; a first electric motor controller configured to supply a variable electrical drive; a second electric motor controller configured to supply a variable electrical drive, the first electric motor controller and the second electric motor controller being both selectively connected to the fuel pump; and a fixed electrical drive, the fixed electrical drive and the second electric motor controller being both selectively connected to the oil pump, the fixed electrical drive functioning as a backup upon a failure of one of the first electric motor controller or the second electric motor controller, the first electric motor controller and the second electric motor controller respectively, operating in conjunction with a motor of the fuel pump, detecting the failure by receiving no power supply or a reduced amount of power supply as compared to normal operation, wherein: in a first configuration, the fuel pump is connected to and driven by the first electric motor controller and the oil pump is connected to and driven by the second electric motor controller, in response to detecting the failure of the first electric motor controller by the first electric motor controller, the fuel and oil system switches into a second configuration by controlling a plurality of switches, in the second configuration the fuel pump is connected to and driven by the second electric motor controller and the oil pump is connected to and driven by the fixed electrical drive, and in response to detecting the failure of the second electric motor controller by the second electric motor controller, the fuel and oil system switches

into a third configuration by controlling the plurality of switches, in the third configuration the fuel pump is connected to and driven by the first electric motor controller and the oil pump is connected to and driven by the fixed electrical drive. 5

2. The fuel and oil system as claimed in claim 1, further comprising a spill valve connected to an output of the oil pump.

3. The fuel and oil system as claimed in claim 1, wherein the first electric motor controller and the second electric motor controller are each a different type of electric motor controller. 10

4. The fuel and oil system as claimed in claim 2, wherein the first electric motor controller and the second electric motor controller are each a different type of electric motor controller. 15

5. The fuel and oil system as claimed in claim 1, further comprising a cooling arrangement.

6. The fuel and oil system as claimed in claim 5, wherein the cooling arrangement includes a first cooling loop arranged to cool the first electric motor controller and a second cooling loop arranged to cool the second electric motor controller. 20

7. The fuel and oil system as claimed in claim 5, wherein the cooling arrangement includes a common cooling loop arranged to cool both the first electric motor controller and the second electric motor controller. 25

8. A gas turbine engine comprising the fuel and oil system as claimed in claim 1.

9. A diesel engine comprising the fuel and oil system as claimed in claim 1. 30

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